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Research Department Report

COVERAGE ASPECTS OF A SINGLE FREQUENCY NETWORK DESIGNED FOR DIGITAL AUDIO BROADCASTING

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Summary

Since the early 1960s, the VHF/FM pilot tone system has been used by broadcasters to supply high quality stereophonic programmes to listeners equipped with fixed receivers and modest gain directional antennas mounted externally at a height of about 10 metres above ground level.

More recently, with the advent of improved radio receivers and digital technology in the reproduction industry, the broadcasters' target audience has changed and listeners now expect high fidelity reception, comparable to CD quality, on their portable and mobile receivers.

In many areas, the demand for high quality can be supplied using the existing VHF/FM networks. There are, however, areas where good portable and mobile reception cannot be obtained, due to shadowing and multipath.

This Report discusses the COFDM channel coding and modulation system developed within the Eureka 147 digital audio broadcasting (DAB) project, which is able to overcome the problems of multipath. Indeed, it can make use of multipath signals. This fact leads to the concept of a Single Frequency Network (SFN) where a single DAB COFDM frequency block can be used to supply five or six programmes to a whole country.

The derivation of minimum required field strength levels for DAB COFDM signals, and the allowances required for high percentage location coverage, necessary for digital systems, are presented together with a spectrum efficiency comparison between SFN and VHF/FM networks.

Theoretical lattice planning, using the CCIR Rec. 370 prediction method, is used initially to illustrate the SFN concept and suggest required effective radiated powers.

The results of SFN coverage studies for the UK, using existing broadcast transmitter sites and utilising both the Rec. 370 and the BBC terrain data based prediction methods, are given. In addition, a possible four frequency block SFN plan for Europe is discussed.

The Report concludes that, in comparison, networks using the Eureka 147 DAB system exhibit a distinct spectrum and power advantage over conventional FM networks.

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1. INTRODUCTION

Since the early 1950s, the Pilot tone frequency modulated (FM) stereo system has been used in VHF Band II for high quality stereo radio transmissions. In planning the FM stereo radio networks, it was assumed that the listeners would install an antenna of modest gain and directivity at about 10 metres above ground level (a.g.l.). Listeners with such domestic installations are, in most European countries, able to receive reasonably high-quality stereophonic programmes for local, regional or national services.

As receiver technology improved, the FM portable and car radio became a reality and receivers became cheaper; the radio target audiences changed from listeners with fixed installations to those using mobile or portable receivers.

Existing FM networks are, of course, able to serve some of these mobile listeners; but in many areas, mobile reception is impaired by selective fading due to shadowing and multipath interference. This is because mobile receiving antennas are generally omnidirectional, so cannot differentiate between the direct signal from the transmitter and any interfering reflected signals. In addition, the mobile receiving antenna is at a low height, making reception even more difficult due to the increased shadowing.

Listeners are now well-acquainted with the high-quality reproduction obtainable from compact disc and other digital technologies, and are now expecting similar quality in radio reception, particularly from their car radios and portables. This, together with the fact that there are about 150 million mobile and portable receivers currently in use in Europe, dictates that a means of serving this vast potential audience with a high-quality digital radio service should be pursued.

A European consortium named Eureka 147 has, in conjunction with the European Broadcasting Union (EBU), developed a system[1,2] capable of overcoming the propagation problems associated with digital transmissions in a mobile channel.

This system is able to accommodate a certain degree of multipath interference. Indeed, it can make constructive use of multipath signals, provided the delay times of the reflected signals are not too great. This leads to the concept of a single frequency network (SFN), since co-channel signals, with the same programme content, can be considered as a special case of multipath interference.

This Report discusses the single frequency network concept in detail; first, from the theoretical point of view, and secondly, explains the planning procedures necessary for providing a nationwide digital audio broadcasting (DAB) system (using both CCIR Recommendation 370[3] and the BBC terrain data-based prediction program[4]).

The results of experimental work carried out by the BBC to assess DAB reception in areas around the cities of London and Birmingham are discussed elsewhere[5,6].

2. BASIC PRINCIPLES OF A SINGLE FREQUENCY NETWORK

A fundamental feature of the Coded Orthogonal Frequency Division Multiplex (COFDM) system is the ability to operate satisfactorily in areas having high levels of multipath propagation. This is largely achieved by the incorporation of a guard interval in the time domain. Provided the longest multipath delay time does not exceed this guard interval, then all received signal components add constructively — effectively on a power-sum basis. As delay times increase above that of the guard interval, the constructive effect of any multipath is reduced, and the interference effect increases. It can be shown[7] that the relationship between the constructive and interference signal power contributions, as a function of delay relative to the guard interval Δ, takes the form indicated in Fig. 1 *(overleaf)*.

It may be noted that Fig. 1 deals with both the normal case where there is a delayed interfering signal, and also where this signal is received in advance of the wanted signal to which the receiver is locked (i.e. a 'pre-echo').

The effect of the interfering contribution is similar to that of noise, or of interference from another digital transmission carrying different programmes. The value of protection ratio required to avoid interference from such signals will depend upon the signal coding strategy, but will be of the order of 10 dB. This value will be assumed hereafter, although it may require to be increased, subject to the value of

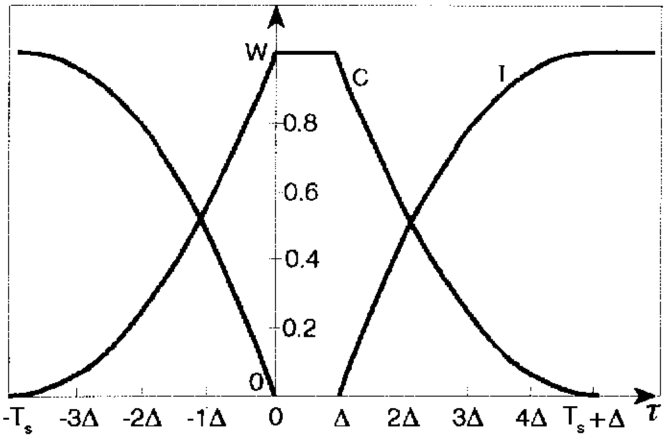


Fig. 1 - Two components of the received power W separated by a time delay τ (single path case).

the 'implementation margin' adopted. From Fig. 1, it may be seen that this 10 dB ratio occurs at a delay of about 1.2 Δ in the case of the parameters used for DAB[2]. From the viewpoint of signal processing within the receiver, a multipath signal is indistinguishable from another transmission, suitably synchronised, carrying the same programmes. It follows, therefore, that a COFDM network, employing only a single frequency block, can be utilised by multiple transmitters over an extensive area without mutual interference; this being subject to the condition that the delay times of all signals received at significant levels do not greatly exceed the guard interval. This may require the guard interval to be greater than required for conventional multipath protection.

This principle is that of the 'Single Frequency Network'.

3. THEORETICAL LATTICE NETWORK CONSIDERATIONS FOR A SINGLE FREQUENCY NETWORK

Consider a uniform lattice network of transmitters sited at the apexes of equilateral triangles of side length D, all radiating the same set of programmes in synchronism.

Assume this to be at VHF and the propagation model to be that of CCIR Rec. 370. This model comprises sets of curves relating field strength to distance, with effective antenna height (h_1) as parameter. (This effective height is defined as the antenna height above the average ground level between 3 and 15 km from the transmitter in the relevant direction.) Various sets of curves are given for various types of paths (e.g. over land and over sea) and for different percentages of time (to represent varying degrees of abnormality in propagation conditions). The following analysis assumes overland propagation with wanted signal contributions derived from the curves for 50% time, and interference contributions from curves for 1% time.

In any such uniform network, the most critical location will be at the centroid of each triangle, since it is here that the composite 'wanted' signal will have its minimum value. It may be noted that:

i) At the centroid, the ratio of distance from the nearest three transmitters to those in the next 'ring' is about 1 : 2. For the propagation model chosen, the corresponding ratio of field strengths is typically at least 16 dB. This implies that, at the two extremes:

   a) The second ring contributes negligibly to the composite wanted signal, even for large values of Δ.

   b) Even for very small values of Δ, the second ring, by itself, would not constitute a major source of interference.

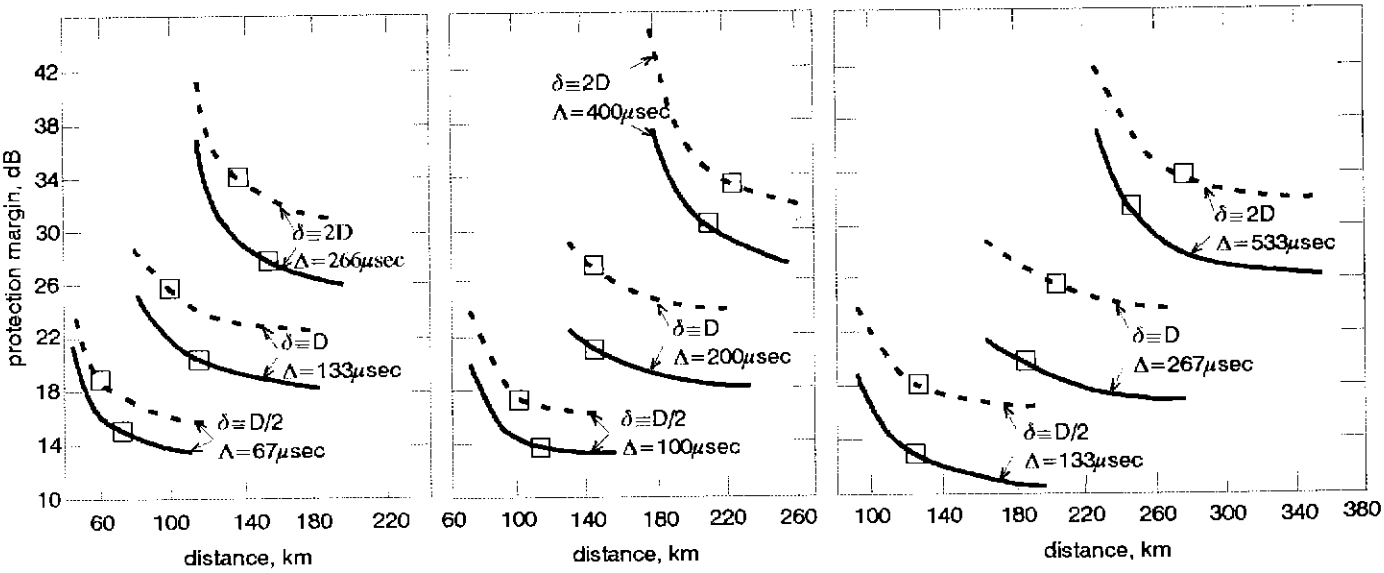
ii) The effect of power-addition of the signal contributions from the closest three transmitters, implies that the composite wanted field strength varies by less than 2 dB over the central ¼ of each elementary triangle (i.e. over the triangle having apexes at the mid-points of these elementary triangles).

Using the propagation model as described above, and the interference weighting factor represented in Fig. 1, it is possible to express the composite wanted and interfering signal contributions in the form of protection margins (i.e. ratio of composite wanted-to-interfering signal levels) against the overall radius of the network from the point under consideration. Such plots are represented in Figs. 2(a), 2(b) and 2(c), for transmitter separation distances, D, of 40 km, 60 km, and 80 km respectively.

Each of these figures shows:

a) The variation for separations D equal to $\delta/2$, δ and 2δ, of the protection margin, as a function of the extent of the network from the centroid of the lattice triangle under consideration. Note that $\delta = \Delta c$; that is, the distance travelled by a radio wave in a time corresponding to the guard interval.

b) The implication of the effective height of the transmitters on this relationship, the calculations being made for heights of 150 m and



(a) Transmitter spacing = 40 km *(b) Transmitter spacing = 60 km* *(c) Transmitter spacing = 80 km*

- - - Effective height = 300 m
—— Effective height = 150 m
□ Distance for which addition of next ring of transmitters increases cumulative interference level by 1 dB
δ = Δc

Fig. 2 - Relationship between protection margins and extent of SFN for various combinations of transmitter separation distances, effective heights, and guard intervals.

300 m. These values were chosen as being typical of those used by main stations in VHF and UHF broadcast networks.

For each of the curves, the minimum distance corresponds to that of the nearest ring of interfering transmitters having a significant contribution, i.e. having a path delay time (relative to the nearest transmitters) in excess of about 1.18Δ. The maximum distance is that at which the addition of the next successive ring of interfering transmitters reduces the protection margin by less than 0.1 dB. Here it should be noted, that the cumulative interfering power is normally proportional to the square of the distance; that is, increases by 6 dB per doubling of path length. However, the propagation model indicates that, over the relevant ranges of distances, a doubling of distance reduces the field strength by about 20 dB. Hence, extending the curves to greater distances has little further effect on protection margin. Moreover, at such distances, for all realistic ratios of δ : D, the protection ratio is independent of whether the interfering transmitters are part of the same SFN, or are carrying different programmes. For each curve in Fig. 2, the point at which the addition of the next interfering ring of transmitters reduces the protection margin by less than 1 dB is shown. Beyond this distance, the margin will be reduced by less than 1 dB, even if the interfering transmitters no longer form part of the same SFN.

Table 1 indicates the relationship between the limiting values of protection margin, effective heights, distances between transmitters and guard intervals.

Table 1: Limiting values of protection margins in uniform lattice networks.

	Separation distance (km)								
	40			60			80		
	Relative guard interval*								
	0.5	1	2	0.5	1	2	0.5	1	2
Effective height (m)	Limit value of protection margin (dB) for specified conditions								
150	13	18	25	11	17	25	10	16	26
300	15	22	31	15	23	31	16	23	32

Table 1 (together with Fig. 2) demonstrates the extent to which increasing effective transmitting antenna height increases protection margins. This is due to the nature of the propagation model in which the influence of effective height is greater at the shorter ranges (representative of the coverage areas) than at the longer ones representing the increasing interference contributions. The same effect may be extrapolated to

* In this context, unity guard interval represents the time taken for a radio wave to traverse the distance between adjacent transmitters, e.g. 200 μsec for a spacing of 60 km.

greater and smaller effective heights. The table also indicates:

a) That, for a given ratio of guard interval to transmitter spacing, the limiting value of margin is largely independent of the spacing. However, since the limiting value is reached at between 3 and 4.5 times the transmitter spacing, this has implications upon re-use distances for the same frequency block.

b) The importance of extending the guard interval to increase protection margins, although, of course, other factors determine the maximum practicable value of this parameter. It may be deduced that, for the range of separation distance D shown in Fig. 2:

   i) A guard interval of less than 0.1 msec is suitable only if a protection margin of less than about 16 dB is acceptable, unless either the extent of the network is very limited, or the effective heights are at least 300 m.

   ii) A guard interval in excess of about 0.25 msec is unnecessary, unless the protection ratio required is to be greater than about 25 dB, except in the case of low effective heights and large values of D.

Taking into account the above considerations, together with those discussed in the following Section, the Eureka 147 Project has determined a guard interval of 0.25 msec for SFNs operating at VHF. Associated with an active symbol period of 1 msec, this gives an overall symbol period of 1.25 msec[8].

4. EFFECT OF LOCATION VARIATIONS AND RECEIVING ANTENNA HEIGHT GAIN IN A SINGLE FREQUENCY NETWORK

In the above theoretical analysis, the propagation curves of CCIR Rec. 370 have been used without corrections for either receiving antenna heights or location variability. The basic curves are considered to represent 50% locations and a receiving antenna height of 10 m a.g.l. The implications of planning, to ensure coverage at a much higher percentage of locations and at car radio antenna heights, are discussed in the following Section in the context of determining minimum field strengths, but they also have implications on the coverage studies discussed above. The effects may be considered separately:

i) Location variability.

For the reason discussed in the following Section, it is necessary to add an allowance, taken as 12 dB, to ensure that the minimum required field strength is achieved at 99% of locations. In practice, all received signals will have a similar variability, and the effect can be ignored only if the signals are perfectly correlated. In reality, this will not be so and there will be two different effects:

a) Where contributions are within the guard interval and thus constructive. In this case, imperfect correlation is an advantage in order to 'fill in' minima; thereby reducing the overall location variability of the composite 'wanted' signal.

b) In other cases, the effect of imperfect correlation is disadvantageous since the required value of mean protection ratio must be increased. In the limit, this increase would have to be by 2×12 dB in the case of a correlation coefficient of -1.

Obviously, effect (a) compensates to some extent for (b), but further work is required to evaluate the effects in practical networks.

ii) Effect of reducing antenna heights.

A primary aim of DAB is to provide high-quality reception in cars and on portable receivers; i.e. at low receiving antenna heights. The implications on minimum required field strengths is discussed in the following Section, and there would be no implication for the previous lattice network study if the (negative) height gain on reducing from 10 m were independent of distance. However, in Section 2.4 of CCIR Rec. 370, it is stated that height gains reduce with increasing path lengths above 50 km. If true, this would increase the relative levels of 'interfering' signal contributions relative to 'wanted' signals at the reduced heights. In the BBC experience, there is no evidence to support this aspect of Rec. 370, but this also is a factor requiring further study.

5. REQUIRED RADIATED POWERS FOR TRANSMITTERS IN A SINGLE FREQUENCY NETWORK

In the previous Section, protection margins have been deduced for various parameters within a uniform triangular lattice network, but without considering what margin represents a limit of service. Here, it is necessary to recognise that, for a COFDM service, the required protection ratio for interference

from another such transmission, is similar to that required for interference from noise. (The other transmission is assumed to have either different programmes, or is an SFN with delay greatly exceeding the guard interval.) The composite interference effect can thus be obtained by power-addition. If, therefore, planning is to be on the basis of a noise-limited service at a protection ratio of 10 dB, then it is necessary to ensure a minimum protection margin for interference of between 16 dB and 20 dB, if the effective margin is not to be reduced by more than between 1 and 0.5 dB. From Fig. 2, it may be seen that this is consistent with the choice of 0.25 msec for the guard interval.

Whilst a noise-limited service is more economical, in terms of radiated powers and spectrum efficiency, it may, as discussed later, be necessary to plan on the basis of an interference-limited network. This implies interchanging the limiting values of C/N and C/I.

The Eureka 147 Group has adopted, as a standard for DAB, a 'block' bandwidth of 1.5 MHz. This is capable of carrying either five or six stereo programmes.

To determine powers required to achieve necessary minimum signal-to-noise levels, certain assumptions are required. These are:

i) Noise bandwidth = 1.5 MHz.

ii) Frequency.

Enquiries carried out within the European Broadcasting Union (EBU) have indicated that a majority of members favour the use of part of Band III. Accordingly, 200 MHz is assumed as a representative frequency.

iii) Receiver Noise Factor.

Whilst recognising that much lower values of noise factor are achievable, it is considered that, for mass-manufactured equipment, a value of between 6 and 10 dB is likely. A value of 8 dB is assumed (corresponding to an equivalent noise temperature of about 2000 K).

From (i) and (ii), substituting in the formula kTB:

Effective receiver noise power

$$= 1.38 \times 10^{-23} \times 2000 \times 1.5 \times 10^{6}$$

$$= 4.14 \times 10^{-14} \text{ W}$$

corresponding to a terminated input voltage of 1.7×10^{-6} V

$$= 4.6 \text{ dB}\mu\text{V (into 70 ohms)}$$

To achieve a signal-to-noise ratio of 10 dB* the required e.m.f.

$$= 4.6 + 10 + 6 = 20.6 \text{ dB}\mu\text{V}$$

For mobile reception, it may be assumed that the receiving antenna will be a whip with an effective gain of, say, −2 dB relative to a dipole. At 200 MHz, the effective length of a half-wave dipole is −6.4 dB relative to 1 m. Hence, an e.m.f. of 20.6 dBμV corresponds to a field strength of 20.6 + 2 + 6.4 = 29 dB(μV/m).

This will be the required field strength at the car receiving antenna. To enable the propagation model of CCIR Rec. 370 to be used, it is more convenient to refer to a receiving antenna height of 10 m. An analysis of a substantial number of height-gain measurements at VHF in suburban and urban areas[9] indicates a median value of 12 dB. Other (unpublished) measurements carried out by the BBC, at 141 MHz in the London area, indicate that mean receiving antenna height gains reduce with increase in building density from 14 dB in rural areas to 4 dB in dense urban areas. The low values in urban areas tend to result from the depression of field strengths at 10 m (implying that, at car antenna heights, the variation of field strength with clutter density may be less than at 10 m). Since the CCIR Rec. 370 propagation model does not take full account of this 'urban depression' of field, it is probably appropriate, for the purpose of this Report, to assume a height-gain value appropriate to rural and suburban areas. A value of 12 dB is assumed, implying an equivalent minimum field strength at 10 m = 41 dB(μV/m).

Finally, there are two further corrections which are less readily quantifiable. These are:

a) A correction for location variations, bearing in mind that the value of 41 dB(μV/m) quoted above represents a median (50%) location value. For an analogue service, it might be sufficient to plan on the basis of providing the minimum nominal field at 90% locations, recognising that this would still provide an acceptable quality at a much higher percentage of locations. Such an assumption is not safe for a digital service, due to the much more rapid rate of impairment below the nominal minimum level. If protection were to be

* Recent studies indicate that a higher value may be required.

planned for 99% locations, the Rec. 370 propagation model requires an allowance of 19 dB. However, the distributions in Rec. 370 are based on measurements of narrowband transmissions (television sound and vision carriers and VHF/FM). The BBC has carried out studies to compare location distributions of CW transmissions with those of DAB (having bandwidths of about 1.5 MHz). These indicate the standard deviations of the wideband transmissions to be 0.6 times those for CW. Hence, the 19 dB allowance in Rec. 370 may be reduced to 12 dB. Similar results were obtained in measurements carried out by Teracom S.R. in Sweden.

An allowance of 12 dB will be assumed, subject to the proviso that no further allowance is made for constructive addition of signal contributions.

b) A correction for the effect of man-made noise. Here, it must be assumed that care will have been taken in suppressing potential interference sources on the vehicle containing the receiver. Nevertheless, tests carried out by the BBC have indicated that, at a frequency of around 200 MHz, external man-made interference in urban areas can typically raise the noise floor by about 10 dB. In suburban areas, it was found that the median level of the noise floor at this frequency was some 4 dB higher than at a frequency (531 MHz) within Band IV.

Assuming that transmitters would be sited to avoid providing minimum field strengths in urban areas, a nominal allowance of 4 dB will be taken for this factor in this analysis. (Part of this allowance is also considered to take account of co-channel interference assuming a C/I ratio of not less than 16 dB.)

Adding the allowances (a) and (b) to the value of 41 dB(μV/m) leads to a required median field strength = 57 dB(μV/m). It is possible to deduce the required effective radiated powers per 1.5 MHz block, when this figure is used, with the 50% time propagation curves of Rec. 370 — this is at 10 m a.g.l. for the lattice configurations already discussed in Fig. 2 and Table 1. These are indicated in Table 2 and are based on the requirements for a car radio service; an additional allowance will be required to ensure adequate coverage to portable receivers in domestic dwellings. A provisional figure of 10 dB has been suggested[6], but further work[10] indicates a median value of 8 dB, with a standard deviation of 3 dB, in ground floors of houses.

These values, which do not include any extra allowance for domestic reception, apply to a complete DAB multiplex and are therefore reduced by 7 or 8 dB for a single stereo programme. This can be favourably compared with ERPs of 50 kW and above, typically used for the main transmitters of VHF/FM National and Regional networks.

Table 2: ERPs required to serve the lattice configuration of Table 1 completely.

Effective Tx. Ant. Ht. (m)	ERP (dB rel. to 1 kw)* for a specified separation distance (km)		
	40	60	80
150	− 3	6	12
300	−10	−2	4

6. EXAMPLE OF SINGLE FREQUENCY NETWORKS USED FOR NATIONAL COVERAGE

A previous Section considered the concept of SFNs in the idealised case of a uniform lattice network. To assess applicability in a practical case, predictions have been carried out for a possible network to provide national coverage within the UK.

Assumptions made are:

i) Transmitters to be co-sited with all main stations of the UHF television network.

ii) Transmitting antennas to be a few metres below the UHF television antenna, or a similar distance below that of the lowest broadcast antenna where the site is shared by other broadcast services.

iii) All these stations assumed to have radiation patterns similar to those for UHF television and a maximum ERP of 5 kW per 1.5 MHz block.

iv) Wanted field strengths based on 50% time conditions and interference on 1% time.

Transition conditions are derived from Fig. 1, assuming a guard interval of 0.25 msec with timing referred to the major contributing source.

The first assessment was carried out using the propagation model of CCIR Rec. 370. Having assessed the coverage achieved both in terms of field strength and protection margins, some additional relays of 500 W ERP were added, and the powers of a few of

* In a 1.5 MHz block (vehicular reception).

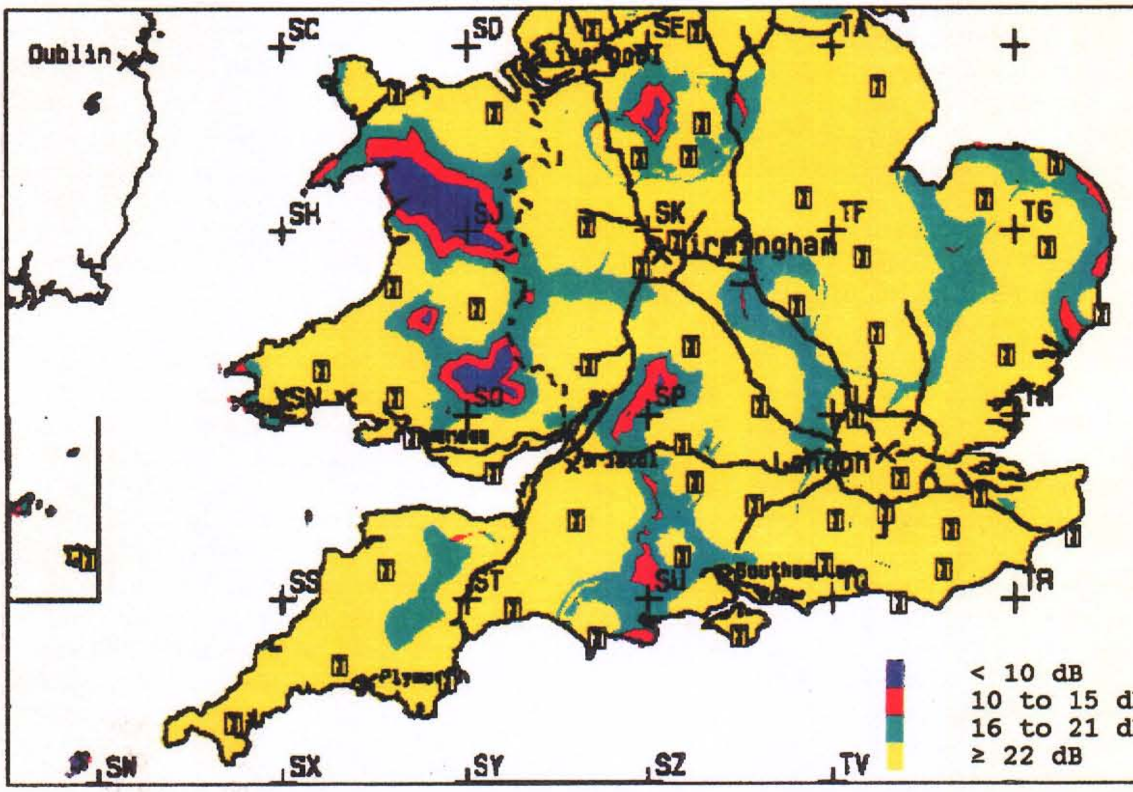


Fig. 3 - Single Frequency Network for southern United Kingdom. Protection margins calculated from CCIR Rec. 370 prediction model.

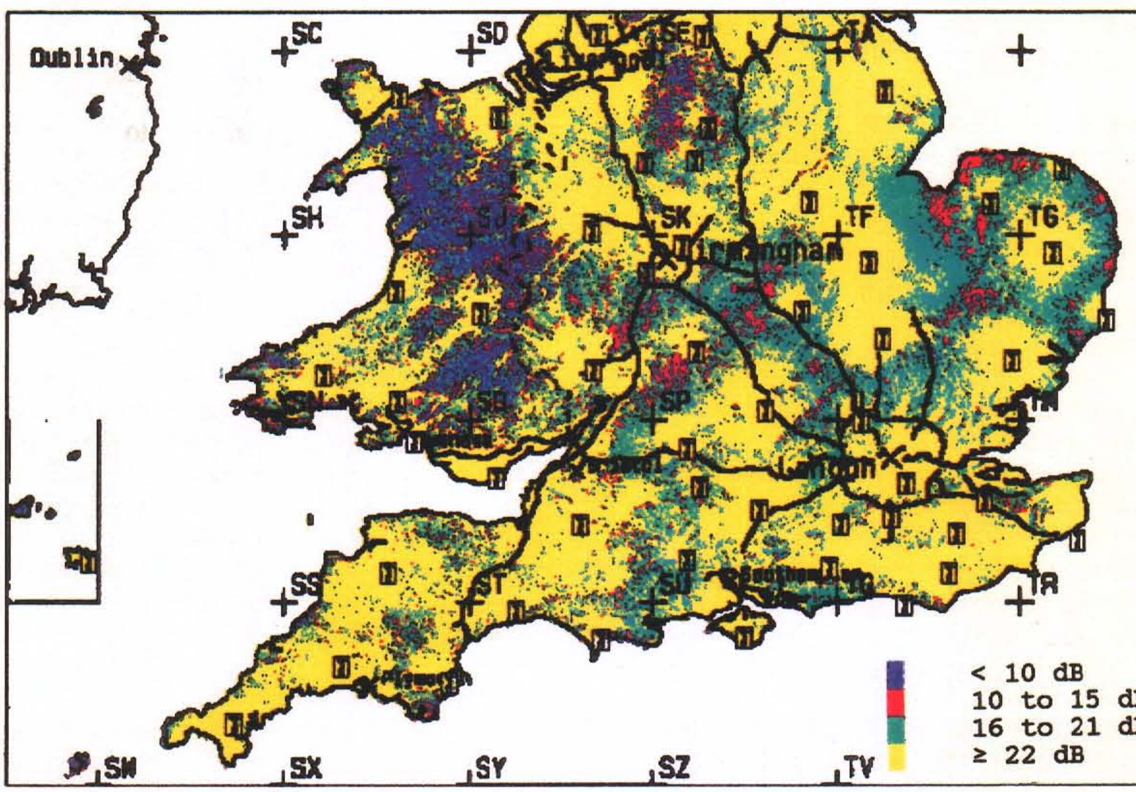


Fig. 4 - Single Frequency Network for southern United Kingdom. Protection margins based on BBC (terrain data based) prediction model.

the original stations with large overlaps reduced to 1.5 kW. In total, about 100 stations were taken into account. No particular attempt was made to ensure complete coverage in the mountainous and sparsely populated areas of Scotland and Central Wales; a much more detailed study is required for such areas.

The result of this analysis, using the Rec. 370 propagation model, is indicated in Fig. 3 *(see previous page)* for Southern England. Here, the resulting protection margin is shown. A corresponding plot of field strength contours, based on appropriate 6 dB banding levels, shows similar coverage — that is, the coverage determined by protection margins corresponds closely to that determined by the field strength for the power chosen. This would seem to be a desirable requisite for efficient planning.

Results of a second study, using a more detailed propagation model based on detailed terrain information, are indicated in Fig. 4 *(see previous page)*. Here, it can be seen that the protection margin distribution is significantly different to that shown in Fig. 3, which was calculated using the statistical Rec. 370 method. This is largely a consequence of taking account of terrain variations near the receiving location. This results in a much greater variation, and a higher probability, that the levels of individual signal contributions will not be inversely related to path length. (NB: In the prediction, it is assumed that the reference transmitter at any location is that producing the highest field strength.)

Fig. 4 shows that a protection margin of at least 10 dB is achieved throughout most of the area; this is with the exception of the mountainous areas, which, as previously discussed, were not planned in detail. However, there are significant areas with margins not exceeding 15 dB. If, therefore, the planning limit is for a signal-to-(noise + interference) ratio of not less than 10 dB, then it is necessary to ensure a carrier-to-noise ratio of at least 16 dB. This may require an adjustment of powers in the relevant areas. The additive contribution of reflected signals, which cannot be taken into account in the prediction, may reduce the local variation in margin.

These studies have now been extended to include further relays (a total of about 200 stations) and the results are described in Ref. 11.

7. OVERALL SPECTRUM REQUIREMENTS FOR SINGLE FREQUENCY NETWORKS

As discussed earlier, an SFN can be extended over a semi-infinite area. However, at the limit of any such area, the protection ratio required between this network and another network carrying a different set of programmes will be about 10 dB or 16 dB (depending on whether planning is based on an interference- or noise-limited network). Clearly, it is not possible to use the same frequency block for different programmes in contiguous areas, although in networks where the transmitter powers are reduced close to the periphery, the frequency re-use distance (with different programmes) would be reduced.

The number of frequency blocks required to produce complete coverages of SFNs is dependent upon the size of the area to be covered by each network. At one limit, the somewhat unrealistic case of a single network for each continent could be considered. Here, a total of three blocks would be adequate, since this would allow for the contiguity, or near-contiguity, of Europe, Africa, and Asia. Obviously, the frequency block used in any one continent could be re-used, for different programmes, over the major part of other continents. For the requirement of a single frequency block for individual countries, three frequency blocks would also suffice in many cases. However, examples can be identified where this would be inadequate. One such area within Europe is that of Luxembourg. This country has borders with three others (France, Belgium and Germany), all of which have borders with each other.

To cater for such circumstances, a minimum of four frequency blocks would be required. Fig. 5 shows a possible distribution of four such blocks to provide different SFNs for each country in Europe. Even with four blocks, it may be noted that the Netherlands is required to share with either France or Luxembourg, the separation from each being only about 60 km.

As the size of each individual SFN reduces (e.g. to provide regional networks within individual countries), so the requirement on spectrum increases. This may be demonstrated in Fig. 5 by assuming separate requirements for the Flemish and French speaking areas in Belgium. Although block 'D' could be used in one of the areas, none of the remaining three blocks would seem appropriate for the other, so a further frequency block would be required. A similar problem would arise if it were required to provide separate programmes to each of the constituent republics of the ex-Yugoslavia. In this case, the difficulty arises due to the shape of the Croatian Republic. In the limit, if areas to be served by each SFN become very small, there is a convergence with conventional planning, for the condition where each transmitter carries a different programme set.

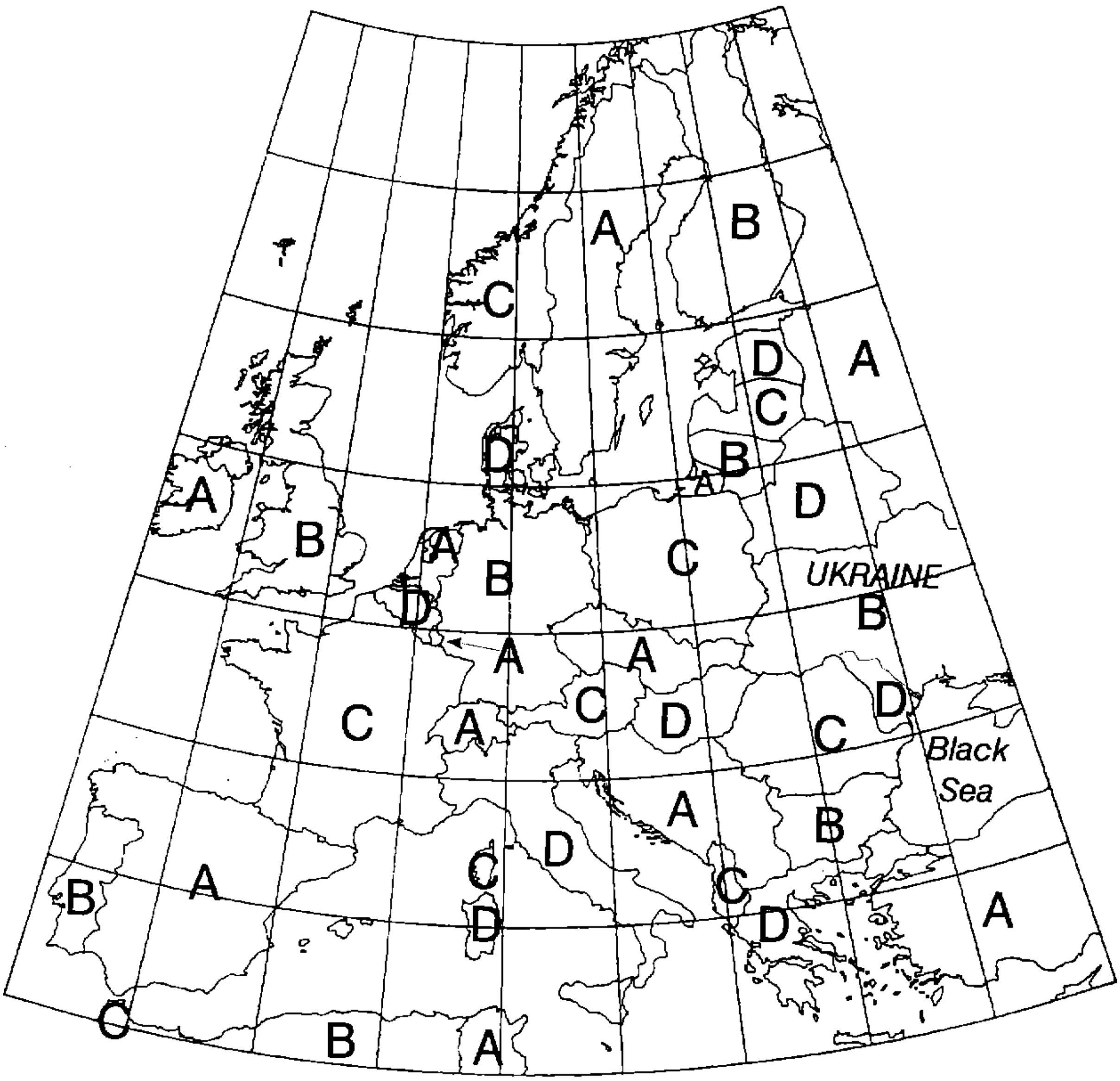


Fig. 5 - Example of distribution of four channel blocks to provide SFNs to individual countries in Europe.

8. COMPARISONS OF SPECTRUM EFFICIENCY BETWEEN SFNs AND VHF/FM NETWORKS

Theoretical analyses, carried out in preparation for the 1982/4 Region 1 VHF/FM Conference, indicated that for complete coverage of an extended area with a single stereo programme, the minimum spectrum requirement is at least 3 MHz. For planning purposes, the protection ratio between FM transmissions is not considered to depend upon the programme content, and thus there is no requirement for transmitters to carry the same progamme.

For COFDM systems, a fundamental basis is the requirement for a number of programmes to be 'packaged' togther in a single frequency block which is common to all the programmes. However, it is still practicable to consider the spectrum requirement per programme by dividing the overall block by the number of programmes contained. On this basis, the spectrum requirement per high quality stereo programme may now be considered to lie between 0.25 and 0.3 MHz. Assuming a requirement for four blocks (as discussed in the previous Section), it follows that the overall spectrum requirement for an SFN providing a single national network to individual countries in Europe, is between 1 and 1.2 MHz. This compares very favourably with that for FM coverage. Moreover, there is also a possibility of using any frequency block allocated to one country over a considerable part of adjacent countries, particularly if these are large.

COFDM also affords a considerable advantage over FM in terms of power requirements. For

example, the configuration indicated in Fig. 3, for a national network in the UK, has a total radiated power of less than 60 kW per programme. The corresponding radiated powers for each existing national network are of the order of 3 MW. Apart from the obvious economic advantages of such a reduction, there are also benefits in terms of ability to share spectrum with other services in adjacent areas.

9. CONCLUSIONS

An introduction to the concept of a digital audio broadcasting SFN has been given, together with the results of an analysis on a theoretical SFN consisting of a uniform lattice of transmitters. The results indicated the optimum spacing and effective heights of the transmitters in the network; also, a set of graphs is presented showing the relationship between protection margin, separation distance and effective height for various guard intervals.

Calculations which enable transmitter powers to be calculated, using CCIR Rec. 370, in order to achieve the necessary signal-to-noise ratios, are given. At Band III, an interim value of minimum field strength of 41 dBμV/m is suggested for a 50% location coverage per 1.5 MHz block. An additional margin of 12 dB is considered to be necessary in order to ensure mobile reception coverage approaching 99%, and 4 dB to account for man-made noise. This gives a total wanted field strength of 57 dBμV/m at a receiving height of 10 m a.g.l. for a noise-limited service. Higher values may be required to allow for co-channel interference and reception within buildings.

The results of two analyses, Rec. 370 and the BBC terrain data based prediction for a UK SFN, are compared; it can be seen that when terrain is taken into account, the results appear to be less clearly defined, as is to be expected, due to local effects. Further work is required to optimise transmitter powers and/or site locations.

Spectrum requirements for SFNs have been discussed and a possible four-block plan for Europe is given. Finally, it is shown that, compared with conventional FM networks, DAB exhibits a distinct spectrum and power efficiency advantage. However, further experimental work is being undertaken in order to firmly establish the planning criteria. This work is essential for efficient DAB service planning, particularly in establishing the minimum required field strength for portable receivers in buildings.

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